

## Tidd PFBC Demonstration Project

**Project completed.**

### Participant

The Ohio Power Company

### Additional Team Members

American Electric Power Service Corporation—  
designer, constructor, and manager  
The Babcock & Wilcox Company—technology supplier  
Ohio Coal Development Office—cofunder

### Location

Brilliant, Jefferson County, Ohio (Ohio Power  
Company's Tidd Plant, Unit No. 1)

### Technology

The Babcock & Wilcox Company's pressurized fluid-  
ized-bed combustion (PFBC) system (under license from  
ABB Carbon)

### Plant Capacity/Production

70 MWe (net)

### Coal

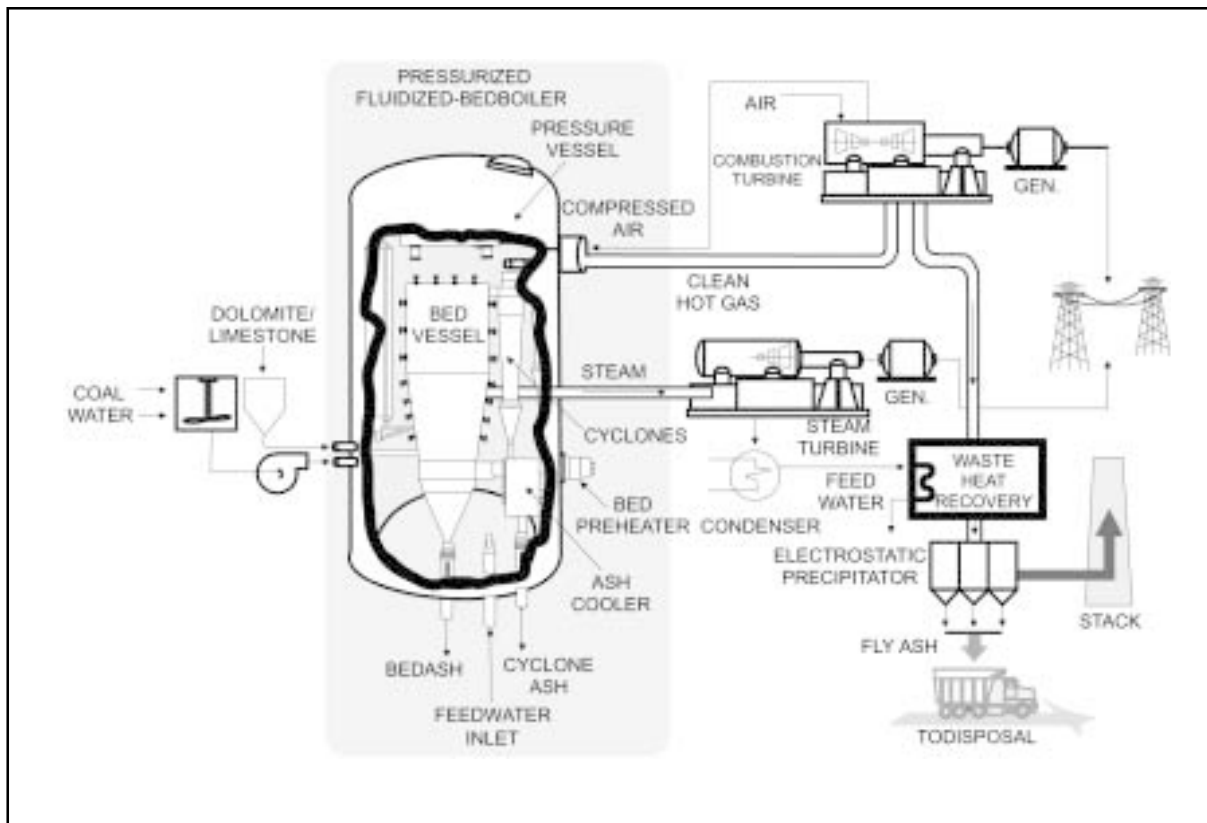
Ohio bituminous, 2–4% sulfur

### Project Funding

Total project cost	\$189,886,339	100%
DOE	66,956,993	35
Participant	122,929,346	65

### Project Objective

To verify expectations of PFBC economic, environ-  
mental, and technical performance in a combined-cycle  
repowering application at utility scale; and to accomplish  
greater than 90% SO<sub>2</sub> removal and NO<sub>x</sub> emission level of  
0.2 lb/10<sup>6</sup> Btu at full load.



### Technology/Project Description

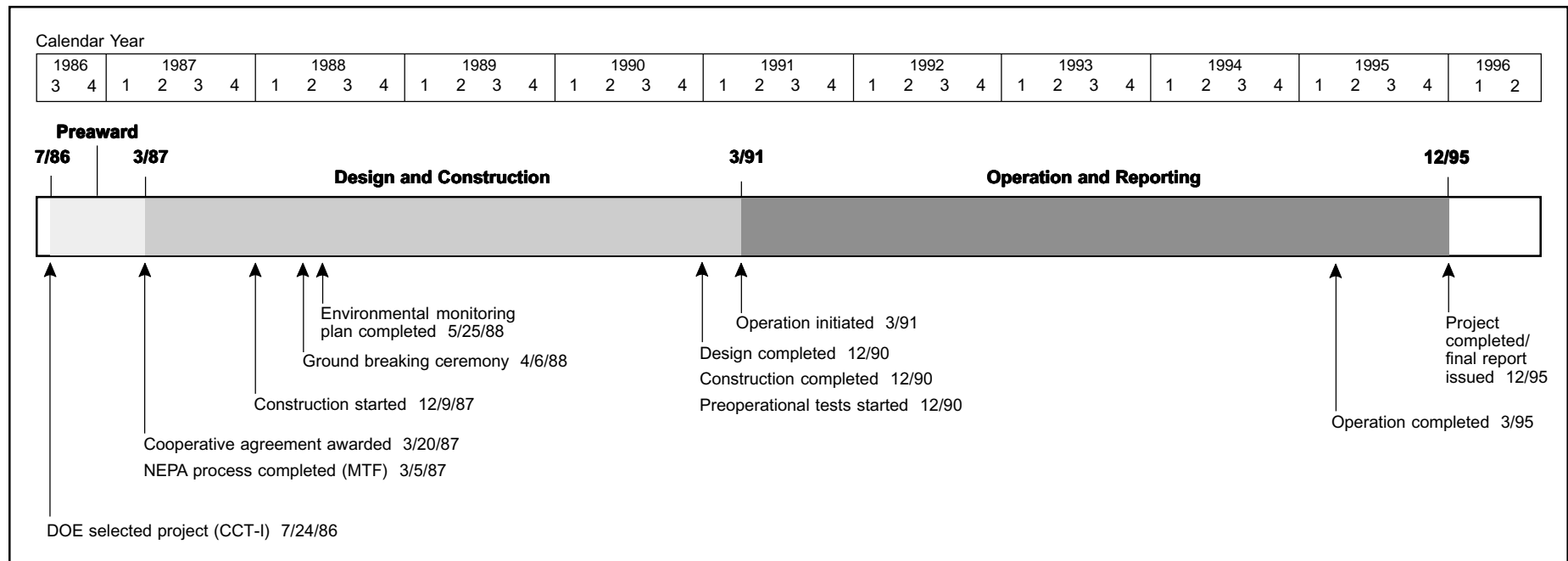
Tidd was the first large-scale operational demonstration  
of PFBC in the United States. The project represented a  
13:1 scaleup from the pilot facility.

The boiler, cyclones, bed reinjection vessels, and associ-  
ated hardware were encapsulated in a pressure vessel 45  
feet in diameter and 70 feet high. The facility was de-  
signed so that one-seventh of the hot gases produced  
could be routed to an advanced particulate filter (APF).

The Tidd facility used a bubbling fluidized-bed combus-  
tion process operating at 12 atm (175 psi). Pressurized  
combustion air is supplied by the turbine compressor to  
fluidize the bed material, which consists of a coal-water  
fuel paste, coal ash, and a dolomite or limestone sorbent.  
Dolomite or limestone in the bed reacts with sulfur to  
form calcium sulfate, a dry, granular bed-ash material,

which is easily disposed of or is usable as a by-product.  
A low bed temperature of about 1,600 °F limits NO<sub>x</sub>  
formation.

The hot combustion gases exit the bed vessel with en-  
trained ash particles, 98% of which are removed when the  
gases pass through cyclones. The cleaned gases are then  
expanded through a 15-MWe gas turbine. Heat from the  
gases exiting the turbine, combined with heat from a tube  
bundle in the fluid bed, generates steam to drive an exist-  
ing 55-MWe steam turbine.



## Results Summary

### Environmental

- Sorbent size had the greatest effect on SO<sub>2</sub> removal efficiency as well as stabilization and heat transfer characteristics of the fluidized-bed.
- SO<sub>2</sub> removal efficiency of 90% was achieved at full load with a calcium-to-sulfur (Ca/S) molar ratio of 1.14 and temperature of 1,580 °F.
- SO<sub>2</sub> removal efficiency of 95% was achieved at full load with a Ca/S molar ratio of 1.5 and temperature of 1,580 °F.
- NO<sub>x</sub> emissions were 0.15–0.33 lb/10<sup>6</sup> Btu.
- CO emissions were less than 0.01 lb/10<sup>6</sup> Btu.
- Particulate emissions were less than 0.02 lb/10<sup>6</sup> Btu.

### Operational

- Combustion efficiency ranged from an average 99.3% at low bed levels to an average 99.5% at moderate to full bed levels.
- Heat rate was 10,280 Btu/kWh (HHV, gross output) (33.2% efficiency) because the unit was small and no attempt was made to optimize heat recovery.
- An advanced particulate filter (APF), using a silicon carbide candle filter array, achieved 99.99% filtration efficiency on a mass basis.
- PFBC boiler demonstrated commercial readiness.
- ASEA Stal GT-35P gas turbine proved capable of operating commercially in a PFBC flue gas environment.

### Economic

- The Tidd plant was a relatively small-scale facility, and as such, detailed economics were not prepared as part of this project.
- A recent cost estimate performed on Japan's 360-MWe PFBC Karita Plant projected a capital cost of \$1,263/kW (1997\$).

## Project Summary

The Tidd PFBC technology is a bubbling fluidized-bed combustion process operating at 12 atmospheres (175 psi). Fluidized-bed combustion is inherently efficient because the pressurized environment enhances combustion efficiency, allows very low temperatures that mitigate thermal  $\text{NO}_x$  generation, promotes flue gas/sorbent reactions that increase sorbent utilization, and produces flue gas energy that is used to drive a gas turbine. The latter contributed significantly to system efficiency because of the high efficiency of gas turbines and the availability of gas turbine exhaust heat that can be applied to the steam cycle. A bed design temperature of 1,580 °F was established because it was the maximum allowable temperature at the gas turbine inlet and was well below temperatures for coal ash fusion, thermal  $\text{NO}_x$  formation, and alkali vaporization.

Coal crushed to one-quarter inch or less was injected into the combustor as a coal/water paste containing 25% water by weight. Crushed sorbent, either dolomite or limestone, was injected into the fluidized bed via two pneumatic feed lines, supplied from two lock hoppers. The sorbent feed system initially used two injector nozzles but was modified to add two more nozzles to enhance distribution.

In 1992, a 10-MWe equivalent APF was installed and commissioned as part of a research and development program and not part of the CCT Program demonstration. This system used ceramic candle filters to clean one-seventh of the exhaust gases from the PFBC system. The hot gas cleanup system unit replaced one of the seven secondary cyclones.

The Tidd PFBC demonstration plant accumulated 11,444 hours of coal-fired operations during its 54 months of operation. The unit completed 95 parametric tests, including continuous coal-fired runs of 28, 29, 30, 31, and 45 days. Ohio bituminous coals having sulfur contents of 2–4% were used in the demonstration.

## Environmental Performance

Testing showed that 90%  $\text{SO}_2$  capture was achievable with a Ca/S molar ratio of 1.14 and that 95%  $\text{SO}_2$  capture was possible with a Ca/S molar ratio of 1.5, provided the size gradation of the sorbent being utilized was optimized. This sulfur retention was achieved at a bed temperature of 1,580 °F and full bed height. Limestone induced deterioration of the fluidized-bed, and as a result, testing focused on dolomite. The testing showed that sulfur capture as well as sintering was sensitive to the fineness of the dolomite sorbent (Plum Run Greenfield dolomite was the design sorbent). Sintering of fluidized-bed materials, a fusing of the materials rather than effective reaction, had become a serious problem that required operation at bed temperatures below the optimum for effective boiler operation. Tests were conducted with sorbent size reduced from minus 6 mesh to a minus 12 mesh. The result with the finer material was a major positive impact on process performance without the expected excessive elutriation of sorbent. The finer material increased the fluidization activity as evidenced by a 10% improvement in heat transfer rate and an approximately 30% increase in sorbent utilization. In addition, the process was much more stable as indicated by reductions in temperature variations in both the bed and the evaporator tubes. Furthermore, sintering was effectively eliminated.

$\text{NO}_x$  emissions ranged from 0.15–0.33 lb/10<sup>6</sup> Btu, but were typically 0.2 lb/10<sup>6</sup> Btu during the demonstration. These emissions were inherent in the process, which was operating at approximately 1,580 °F. No  $\text{NO}_x$  control enhancements, such as ammonia injection, were required. Emissions of carbon monoxide and particulates were less than 0.01 and 0.02 lb/10<sup>6</sup> Btu, respectively.

## Operational Performance

Except for localized erosion of the in-bed tube bundle and the more general erosion of the water walls, the Tidd boiler performed extremely well and was considered a commercially viable design. The in-bed tube bundle experienced no widespread erosion that would require significant maintenance. While the tube bundle experi-



The PFBC demonstration at the repowered 70-MWe unit at Ohio Power's Tidd Plant led to significant refinements and understanding of the technology.

enced little wear, a significant amount of erosion on each of the four water walls was observed. This erosion posed no problem, however, because the area affected is not critical to heat transfer and could be protected by refractory.

The prototype gas turbine experienced structural problems and was the leading cause of unit unavailability during the first 3 years of operation. However, design changes instituted over the course of the demonstration proved effective in addressing the problem. The Tidd demonstration showed that a gas turbine could operate in a PFBC flue gas environment.

Efficiency of the PFBC combustion process was calculated during testing from the amount of unburned carbon in cyclone and bed ash, together with measurements of the amount of carbon monoxide in the flue gas. Combustion efficiencies averaged 99.5% at moderate to full bed heights, surpassing the design or expected efficiency of 99.0%.

Using data for typical full-load operation, a heat rate of 10,280 Btu/kWh (HHV basis) was calculated. This corresponds to a cycle thermodynamic efficiency of 33.2% at a point where the cycle produced 70-MWe of gross electrical power while burning Pittsburgh No. 8 coal. Because the Tidd plant was a repowering application at a comparatively small scale, the measured efficiency does not represent what would be expected for a larger utility-scale plant using Tidd technology. Studies conducted under the PFBC Utility Demonstration Project showed that efficiencies of over 40% are likely for a larger, utility-scale PFBC plant.

In summary, the Tidd project showed that the PFBC system could be applied to electric power generation. Further, the demonstration project led to significant refinements and understanding of the technology in the areas of turbine design, sorbent utilization, sintering, post-bed combustion, ash removal, and boiler materials.

Testing of the APF for over 5,800 hours of coal-fired operation showed that the APF vessel was structurally adequate; the clay-bonded silicon carbide candle filters were structurally adequate unless subjected to side loads from ash bridging or buildup in the vessel; bridging was precluded with larger particulates included in the particulate matter; and filtration efficiency (mass basis) was 99.99%.

### Economic Performance

The Tidd plant was a relatively small-scale demonstration facility, so detailed economics were not prepared as part of this project. However, a recent cost estimate performed on Japan's 360-MWe PFBC Karita Plant projected a capital cost of \$1,263/kW (1997\$).

### Commercial Applications

Combined-cycle PFBC permits use of a wide range of coals, including high-sulfur coals. The compactness of bubbling-bed PFBC equipment allows utilities to significantly increase capacity at existing sites. Compactness due to pressurized operation reduces space requirements

per unit of energy generated. PFBC technology appears to be best suited for applications of 50 MWe or larger. Capable of being constructed modularly, PFBC generating plants permit utilities to add increments of capacity economically to match load growth. Plant life can be extended by repowering with PFBC using the existing plant area, coal- and waste-handling equipment, and steam turbine equipment.

The 360-MWe Karita Plant in Japan, which uses ABB Carbon P800 technology, represents a major move toward commercialization of PFBC bubbling-bed technology. A second-generation P200 PFBC is under construction in Germany. Other PFBC projects are under consideration in China, South Korea, the United Kingdom, Italy, and Israel.

The Tidd project received *Power* magazine's 1991 Powerplant Award. In 1992, the project received the National Energy Resource Organization award for demonstrating energy efficient technology.



Coal and sorbent conveyors can be seen just after entering the Tidd plant.

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